Light curve solutions for 50 eclipsing binaries in the Small Magellanic Cloud. III

Valentin Ivanov, Diana Kjurkchieva
University of Shumen, Bulgaria
viva_nov@abv.bg; d.kyurkchieva@shu-bg.net
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Abstract. The results from modeling of the light curves of 50 eclipsing stars in the Small Magellanic Cloud (SMC) obtained in the framework of the project OGLE are presented. We established that the components of the target binaries were hot stars with big radii, masses, luminosities and low densities.
Key words: stars, eclipsing stars, SMC

Решения на кривите на блясъка за 50 затъмнителни двойни звезди от Малкия Магеланов Облак. III

Валентин Иванов, Диана Кюркчиева

Представени са резултати от моделирането на кривите на блясъка на 50 затъмнителни звезди от Малкия Магеланов Облак, получени в рамките ka проекта OGLE. Ние установихме, че компонентите на изследваните двойки са звезди с големи радиуси, маси, светимости и ниски платности.

Introduction

The study of eclipsing binaries is very important for the modern astrophysics because these stars are one of the most useful sources of information about the stellar parameters. The investigation of eclipsing binaries in large and homogenous sample gives a possibility to improve the empirical statistical relations between the stellar parameters.

The microlensing project OGLE (Udalski et al. 1998) monitored millions of stars in the Magellanic Clouds during the last years. The huge photometric database is available also for investigations of the detected variable stars.

Typically, the OGLE catalogs contain about 400 data points in I-band and about 30 points in V and B band for each variable star. The errors of the magnitude measurements are: 0.005^m for the brightest stars ($I < 15^m$) and 0.08^m for stars with $15^m \leq I \leq 19^m$.

We began to study the eclipsing binaries in SMC in order to get their global parameters by simultaneous fitting of the data in the three colors. This paper presents the results from the light curve solutions of the next 50 eclipsing stars with circular orbits in SMC.

1 Procedure

Our modeling procedure consists of the following stages (see detailed description in Kjurkchieva & Ivanov 2006):

(a) Preliminary light curve solution on the basis of several known empirical relations (Flower 1996, Zaritsky et al. 2002, Graczyk 2003);

(b) Fast initial light curve solution by the code Binary Maker 3 (Bradstreet & Steelman 2004);

(c) Final simultaneous multicolor solution using the code DC (Wilson & Van Hamme 2003) that gives the values of the varied parameters and their errors.

After the light curve solution we calculated the global stellar parameters as it foolows:

(a) The visual magnitudes V_i of the components were obtained by the Pogson formula on the base of the known total out-eclipse magnitude V of the binary (from the OGLE data) and the ratio $k = l_1/l_2$ of the relative luminosities l_i (determined earlier by the light-curve solution):

$$V_1 = V + 2.5\lg(1 + 1/k) \quad V_2 = V + 2.5\lg(1 + k). \tag{1}$$

(b) The absolute magnitudes were calculated by the known distance to the SMC (DM $=18.9^m$, ~ 60 kpc) and taking into account the intergalactic reddening

$$M_i^V = V_i - DM - RE_{(B-V)} \tag{2}$$

where R=3.1 was the total absorption to the SMC and $E_{(B-V)}$ was the color index for the place of the corresponding binary (SMC Extinction Retrieval Service, Zaritsky et al. 2002).

(c) The absolute bolometric magnitudes were obtained using the bolometric corrections from the Flower' table (1996)

$$M_i^{bol} = M_i^V + BC_i. \tag{3}$$

After that one can obtain the absolute luminosities

$$2.5\lg L_i = 4.75 - M_i^{bol}. \tag{4}$$

(d) The orbital separation a was determined from the equation

$$\lg a = 0.2(M^{bol} - M_1^{bol}) - \lg r_1 - 2.5\lg T_1 + 7.524. \tag{5}$$

It is consequence from the relations

$$L_i = 4\pi R_i^2 \sigma T_i^4 \tag{6}$$

$$R_i = a r_i \tag{7}$$

and formula (4).

(e) The stellar masses $\mathbf{M}_i$ were calculated by the statistic relations mass-luminosity appropriate for the metallicity of SMC stars (Graczyk 2003):

$$3.664\lg \mathbf{M}_i = \lg L_i - 0.38. \tag{8}$$

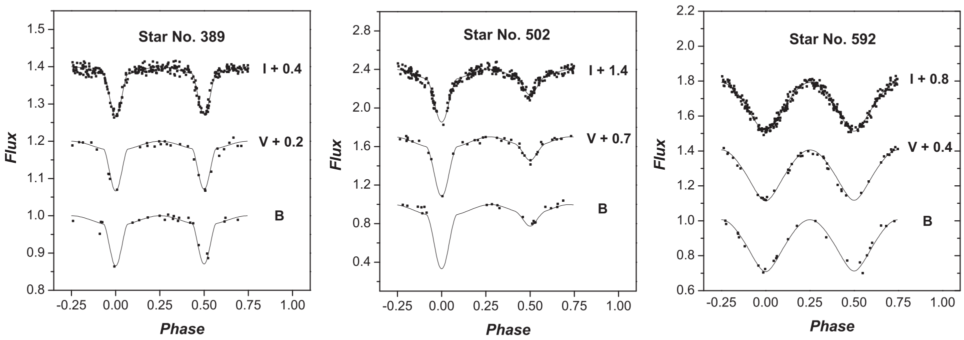

Fig. 1. Illustration of 3-color light curve solutions of detached binary (left panel), semidetached binary (middle panel) and contact binary (right panel)

2 Results

We chose to model 50 eclipsing stars with circular orbits in SMC which B and V data have enough points into the eclipses. In opposite case the light curve solution is quite undetermined.

Figure 1 illustrates the fits of our light curve solutions for contact (C), semidetached (SD) and detached (D) binary.

Tables 1-2 present the values of the parameters obtained by our light curve solutions and the calculations of the global parameters of the stellar components. The first four columns of these Tables show respectively the star number, type of the obtained configuration (Sd1/Sd2 means semidetached binary which primary/secondary star fills-in its Roche lobe); orbital period P (in days); out-of-eclipse magnitude in V color. The next four columns present the values of the fitted parameters: temperatures of the components T_i; mass ratio q; orbital inclination i; mean relative stellar radii r_i. The last four columns show the global parameters of the stellar components (in solar units): luminosities L_i; radii R_i; masses $\mathbf{M}_i$ and densities ϱ_i.

In order to get a better fit to 8 light curves we had to put cool spot on the stellar components. The spotted solutions are marked by asterisks in the second column of Tables 1-2.

The statistical analysis of the obtained parameters of the light curve solutions for the 50 target systems in SMC leads to three conclusions.

(i) The temperatures of the components are in the range 3800-32600 K and their distribution has a maximum in the range 10000-15000 K.

(ii) The relative stellar radii are between 0.137 and 0.437 and their distribution has a maximum in the range 0.3-0.35. About 32 % of the binaries have bigger secondary component ($r_2/r_1 > 1$). 32 targets of our sample were reproduced by detached configurations, 10 binaries were fitted by semidetached configurations (nine were Sd2 and one Sd1) and 8 systems turned out contact configurations.

(iii) The photometric mass ratio of the binaries is between 0.14 and 1.53 with a maximum around 0.8-1.

Table 1. Global parameters of the first 25 eclipsing stars of our sample

No	Type	P	V	T_i	q	i	r_i	L_i	R_i	$\mathbf{M}_i$	ρ_i
163	C	10.31	16.434	11900	0.9	42.4	0.429	1062	7.69	5.17	0.01141
				10000			0.411	416	7.37	6.02	0.01512
164	D	1.28	17.37	12200	1.03	75.2	0.238	283	3.78	3.60	0.06718
				12800			0.275	473	4.36	6.18	0.07499
309	C	0.47	18.66	12100	0.93	79.3	0.403	116	2.45	2.82	0.19196
				12100			0.390	104	2.38	4.38	0.32777
318	C	0.56	17.36	15500	0.96	54.3	0.399	665	3.59	4.55	0.09909
				14900			0.392	548	3.52	6.35	0.14604
367	D	1.11	17.75	15700	0.45	71.7	0.298	780	3.79	4.75	0.08792
				10500			0.215	64	2.74	3.80	0.18595
385	C*	2.56	15.69	22100	1	40.5	0.385	7322	5.86	8.76	0.04381
				20900			0.385	5745	5.86	9.14	0.04571
386	D	73.75	17.700	4900	0.72	77.3	0.159	114	14.88	2.81	0.00086
				4800			0.252	269	23.59	5.51	0.00042
389	D	1.25	15.83	20500	0.57	71.4	0.260	5295	5.79	8.01	0.04154
				19900			0.230	3726	5.13	8.62	0.06406
392	Sd2	1.84	13.55	29500	0.83	76.1	0.372	88439	11.42	17.28	0.01165
				29200			0.362	81172	11.11	12.27	0.00899
393	C	0.43	18.568	8400	1.04	72.3	0.399	61	3.71	2.37	0.04679
				8500			0.392	1631	3.64	7.64	0.15873
395	D	1.17	18.195	10900	0.85	76	0.275	163	3.59	3.10	0.06717
				9800			0.246	78	3.21	4.04	0.12257
396	D	1.95	16.134	21200	0.46	70.7	0.300	5423	5.48	8.07	0.04935
				15000			0.249	943	4.55	6.99	0.07457
399	D	3.61	16.31	10100	1.29	83.2	0.137	466	7.07	4.13	0.01172
				11600			0.149	1085	7.72	7.16	0.01561
402	D*	3.61	16.772	11600	0.82	77.6	0.185	758	6.84	4.72	0.01480
				9100			0.187	239	6.93	5.37	0.01620
407	D	0.78	18.54	10400	0.28	76.1	0.437	144	3.71	3.00	0.05891
				8100			0.255	17	2.17	2.21	0.21775
409	D	2.39	15.1	25200	1	76.8	0.258	15691	6.59	10.78	0.03780
				24200			0.246	12192	6.28	10.03	0.04059
425	D*	0.87	16.36	8100	1.01	59.3	0.335	462	10.95	4.12	0.00315
				8200			0.350	531	11.43	6.31	0.00425
449	Sd1	138.06	17.08	5300	0.71	71	0.409	584	28.76	4.39	0.00019
				3900			0.309	153	21.74	4.84	0.00047
463	D	30.44	19.1	5700	0.14	89	0.187	44	6.81	2.17	0.00688
				5100			0.219	35	8.00	3.10	0.00608
466	D	0.77	16.56	12600	1	62.1	0.366	814	6.01	4.81	0.02228
				12200			0.371	722	6.10	6.68	0.02958
472	D	3.63	15.19	13200	0.47	82	0.323	4621	13.04	7.72	0.00350
				10000			0.314	1191	12.69	7.27	0.00358
502	Sd2	1.80	18.28	13000	0.57	81.8	0.198	201	2.81	3.28	0.14917
				8400			0.330	76	4.68	4.01	0.03923
505	C	0.47	17.89	9300	1.01	48.2	0.415	131	4.42	2.92	0.03404
				9400			0.413	136	4.40	4.70	0.05550
508	D	2.28	16.16	20000	0.42	73.9	0.314	5635	6.27	8.15	0.03319
				10600			0.305	339	6.09	5.78	0.02566
509	D	249.69	16.42	5600	0.86	74.4	0.222	1003	33.75	5.09	0.00013
				4300			0.137	169	20.87	4.96	0.00055

Table 2. Global parameters of the second 25 eclipsing stars of our sample

No	Type	P	V	T_i	q	i	r_i	L_i	R_i	$\mathbf{M}_i$	ρ_i
516	D	1.66	17.49	16200	0.92	83	0.215	744	3.47	4.69	0.11250
				15500			0.192	495	3.11	6.23	0.20798
518	D	4.63	18.13	3800	1.14	69.3	0.241	5	4.99	1.17	0.00948
				10500			0.327	269	6.76	5.51	0.01790
527	D*	4.61	14.133	32600	0.42	85.4	0.265	70367	8.34	16.24	0.02810
				25400			0.316	34031	9.94	11.24	0.01148
539	D	1.04	18.08	9500	1.23	86.8	0.273	51	2.65	2.26	0.12247
				15100			0.330	656	3.19	6.56	0.20241
544	D	1.78	17.61	18500	0.77	78	0.218	884	2.90	4.92	0.20175
				15100			0.217	381	2.89	5.92	0.24704
546	D*	1.40	17.05	14300	0.71	69.8	0.291	756	4.49	4.71	0.05218
				14100			0.287	695	4.43	6.63	0.07657
553	Sd2*	3.03	16.04	18100	0.48	65.7	0.362	4633	6.94	7.73	0.02319
				12100			0.316	616	6.06	6.49	0.02936
561	Sd2	6.38	17.75	22100	0.55	83	0.165	893	2.05	4.93	0.57895
				12100			0.327	289	4.04	5.59	0.08487
570	D	1.11	18.05	12200	0.94	83.1	0.273	204	3.21	3.30	0.10020
				12100			0.275	199	3.23	5.15	0.15319
573	D	1.28	17.42	14100	0.91	90	0.256	519	3.83	4.25	0.07601
				13900			0.252	220	3.76	5.27	0.09932
589	Sd2	1.19	16.34	25200	0.58	89.6	0.345	6790	4.34	8.58	0.10566
				18500			0.332	1941	4.17	7.85	0.10884
592	C	0.63	16.428	26400	1	64.7	0.411	4817	3.33	7.81	0.21284
				26000			0.411	4527	3.33	8.85	0.24126
595	D	1.94	15.94	13500	0.83	75.3	0.284	2038	8.28	6.18	0.01094
				10100			0.356	819	10.38	6.83	0.00613
597	D	3.66	17.76	3900	1.53	82.1	0.236	4	4.54	1.15	0.01233
				14500			0.279	857	5.35	6.88	0.04504
606	Sd2	1.53	17.35	18400	0.33	80.6	0.304	1507	3.83	5.69	0.10149
				11300			0.286	161	3.62	4.90	0.10414
607	D	4.16	17.84	9900	0.18	78.6	0.213	281	5.72	3.60	0.01932
				5100			0.234	27	6.28	2.80	0.01138
609	Sd2*	1.87	14.78	25400	0.52	80	0.336	21929	7.67	11.81	0.02628
				23900			0.323	15868	7.37	10.34	0.02599
611	D	0.83	18.38	18600	0.89	85.5	0.347	445	2.04	4.08	0.48420
				14900			0.347	180	2.04	5.03	0.59803
615	D	1.33	15.75	26900	0.69	66.9	0.398	15043	5.66	10.66	0.05889
				18000			0.319	2046	4.54	7.91	0.08510
617	D	4.16	17.9	21700	0.9	69.6	0.335	1057	2.31	5.16	0.42209
				18700			0.298	473	2.06	6.18	0.71399
618	C	419.81	15.04	4700	0.72	31.3	0.428	4464	101.08	7.65	0.00001
				3800			0.371	2353	87.56	8.08	0.00001
620	D	0.91	17.44	12800	0.89	63.9	0.357	451	4.33	4.09	0.05053
				11700			0.356	294	4.32	5.61	0.07006
631	D*	0.91	17.47	16100	0.98	67.1	0.370	752	3.54	4.70	0.10692
				15900			0.359	667	3.43	6.58	0.16374
634	Sd2	1.28	16.82	23100	0.57	86.6	0.351	3118	3.50	6.94	0.16288
				17400			0.330	944	3.29	6.99	0.19782
636	Sd2	0.89	17.67	17500	0.54	73.9	0.346	874	3.23	4.90	0.14673
				13000			0.326	219	3.03	5.26	0.18964

Conclusion

The analysis of the obtained global parameters of the 50 eclipsing stars with circular orbits in SMC leaded to several conclusions.

(1) The most of the components are hot stars. This result is in correspondence with the colors reported by Udalski et al. (1998) as well as with the fact that the spectra of the irregular galaxies (as SMC) are similar to the spectra of hot star.

(2) All stellar components have big radii, masses and luminosities. This result is not surprising because only the brightest stars may be observable at such long distance (in other galaxy).

(3) All stellar components have low densities. This is due to the impossibility to observe dwarf stars at such distance.

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